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Warming temperatures are impacting the hydrometeorological regime of Russian rivers in the zone of continuous permafrost

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Tables S1 – S4 designations

The cells filled with grey color correspond to statistically significant trends with $p<0.10$. If any value is bold, it has significance $p<0.05$; if a value is in italics, it has significance $0.05<p<0.10$. In Tables 4 (precipitation) and 7-9 (streamflow) each cell with significant trend contains three numbers: 1) the value of total change for the whole period of observations in the characteristic unit (for example, mm) 2) percentage of total change (%); 3) where available – the year of change point or letter “m” for monotonical trend. If there is neither year, nor “m”, the Pettitt’s test was not carried out due to too many gaps in the data. Statistically significant trend values are divided into 4 groups and marked with different colors accordingly: change points around **1966 – red**, **1970-1985 – green**, **1986-1995 – violet**, **1996 and later – yellow**. Monotonous trends and where change points were not available due to too many gaps in the data **are in black**. For streamflow, the year of change point marked with * indicates that the gauge has a long-term series of more than 70 years with change point in about 1966 and no significant trend after that period (last 50 years). In some cases, a second year of change point is given in brackets, as estimated with Buishand range test.

Table S1: Detected changes of monthly and annual air temperature (°C) and change points (year).

Index	Period	1	2	3	4	5	6	7	8	9	10	11	12	Avg	*CPY
Yana River basin															
21931*	1961-2015	2.8	0.7	2.9	**4.1**	**3.1**	2.0	1.4	**3.0**	1.7	1.8	3.0	2.1	**2.2**	**0.40**
24261	1966-2012	*3.1* m	-3.3	-0.1	1.7	**3.1 m**	2.3	2.2	2.4	-0.2	0.5	**3.6 2000**	-0.1	**1.4 m**	**0.30**
24266*	1969-2015	**5.6**	2.1	0.0	**2.3**	**3.8**	**1.7**	**3.2**	**2.1**	0.5	0.6	1.9	**4.5**	**2.1**	**0.45**
24371	1942-2015	**3.5 1990**	0.7	1.0	**3.4 1967**	**3.3 1970**	0.8	*1.5 m*	0.3	-0.4	0.7	**4.1 1982**	1.9	**1.8 1982**	**0.24**
Indigirka River basin															
21946	1939-2015	1.4	0.4	1.4	2.8	1.1	0.4	**1.5** *1986*	**2.1** *2001*	**2.9 1979**	**4.4 1993**	**4.7 1993**	2.5	**2.3 1987**	**0.30**
24076	1960-2015	**4.6** *1992*	1.8	2.5	**3.7** *2002*	**3.1** *2004*	0.9	1.8	**2.0 1994**	**1.6 m**	1.7	3.2	3.1	**2.5 1987**	**0.45**
24382	1938-2015	**5.1 1975**	**3.0 1978**	**4.1 1983**	**4.5 1980**	**3.5 1987**	1.1	**2.2 1986**	1.4	1.3	**4.5 1987**	**6.3 1983**	**5.2 1978**	**3.6 1987**	**0.46**
24585*	1966-2012	-1.6	0.1	**4.0**	1.4	1.8	**2.2**	1.7	0.7	0.3	1.5	**4.7**	**2.9**	**1.7**	**0.36**
24588	1957-2015	2.4	0.1	**3.3 2000**	1.0	1.2	1.4	*1.6* m	1.0	0	2.1	**3.8 m**	2.4	**1.8 1979**	**0.31**
24679*	1942-2015	1.7	-0.9	**2.5**	**1.9**	**2.8**	**1.9**	1.0	-0.6	-0.7	0.5	2.3	1.2	**1.2**	**0.16**
24684	1957-2015	1.3	-0.3	**3.0 1999**	1.1	1.9	**2.0 1988**	**2.1 1990**	1.2	0.6	1.1	**5.7 1983**	3.2	**2.1 1979**	**0.36**
24688	1935-2015	**3.7 1973**	0.8	**4.1 1988**	**2.8 1969**	**2.7 1970**	**2.1 1985**	**1.6 1993**	0.7	0.5	1.4	1.4	1.8	**2.0 1979**	**0.25**
24691	1966-2015	1.6	-0.5	**4.0 1999**	1.3	1.9	1.4	**2.2 1987**	1.0	0.3	**3.1 1993**	**6.2 1983**	**5.0 1994**	**2.3 1993**	**0.46**

Table S2: Detected changes of monthly and seasonal precipitation (mm) and change points (year), 1966-2015.

Index	Period	1	2	3	4	5	6	7	8	9	10	11	12	Year	Cold (10-4)	Warm
Yana River basin																
21931	1966-2015	2.5	-1.4	3.0	0.0	-0.7	-10.0	-12.9	**-26.0** **-71**	-6.3	-1.5	4.5	1.1	-36.2		
24261	1966-2012	-1.7	-1.8	-1.2	-4.5	5.3	8.1	17.9	6.5	2.0	-4.2	-0.3	**-3.5** **-67**	32.6		
24266	1966-2015	-2.9	-2.9	-1.3	-3.1	2.2	5.8	3.0	5.1	7.3	-3.9	-1.9	-5.0	9.0	**-19.3** **-36** **1979**	
24371	1966-2015	-1.3	-1.7	-0.7	-4.6	1.8	13.9	5.7	8.5	5.5	-4.8	-2.5	**-4.2** **-63** **1985**	10.8	**-23.6** **-46** *1996*	
Indigirka River basin																
24382	1966-2015	**-6.7** **-92** **1986**	**-4.8** **-71** **m**	-2.9	-1.0	4.3	5.2	3.3	7.1	4.1	0.0	0.8	-4.3	11.8	*-16.0* *-29* m	
24585	1966-2015	**-4.2** **-58**	-2.6	1.2	-0.8	-0.2	5.5	-8.9	5.5	14.6	2.7	2.9	-3.0	15.5		
24588	1966-2015	**-4.3** **-68**	-1.5	0.0	-2.8	1.7	-12.1	-8.8	2.8	-0.2	-1.7	-1.7	-1.9	-26.6	*-14.9* *-26*	
24679	1966-2015	**-4.0** **-90**	**-3.3** **-121**	-2.1	-0.4	1.3	**20.7** **44**	-28.3	-3.2	13.8	-1.7	-0.1	-1.0	41.6	*-13.0* *-30*	
24684	1966-2015	-2.4	-0.6	1.8	0.3	-1.6	2.1	-9.0	-4.5	3.9	0.5	2.7	-1.1	13.7		
24688	1966-2015	**-4.4** **-60** **1980**	**-3.0** **-44** **1994**	-1.3	-0.6	0.5	7.5	0.1	9.7	8.5	-1.0	3.0	-4.5	40.9		**53** **34** **m**
24691	1966-2015	**-5.5** **-62** **1987**	-3.6	1.1	1.7	-3.5	9.2	-2.8	12.3	5.8	3.0	3.5	-3.8	15.9		
24076	1966-2012	-2.0	-2.6	1.6	-3.8	3.1	**21.8** **49**	9.4	23.7	**15.3** **49**	5.0	4.0	-1.9	58.5		
21946	1966-2012	-5.3	-4.8	2.8	0.0	-2.1	-14.4	**-22.9** **-73**	-11.5	-1.7	5.6	5.0	3.3	-42.9		**-48** **-60**

Table S3: Detected changes of monthly and annual streamflow (mm and %) and change point (year) and freshet onset dates. The Yana River basin

ID	Period	Area, km^2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Freshet onset dates
3478	1953-2007	22.6	NA	NA	NA	NA	6.9	14.0	12.9	**13.0 50 1981**	**7.1 54 m**	**0.12 31 1987**	0.00	0.00	**79 69 1988**	*5.8*
3479	1956-2014	7570	NA	NA	NA	NA	5.6	**12.8 64 m**	4.6	**8.3 54** *1987*	**5.5 67 m**	0.1	0.0	NA	38	
3474	1949-2007	8290	NA	NA	NA	NA	**7.5 54 1964***	-6.7	*-26 -38 m*	8.7	8.4	**4.5 78 1991**	0.3	0.0	-7	**10**
3424	1957-2015	16700	0.0	NA	NA	NA	2.9	7.3	-5.5	0.4	**5.7 53 1982**	**0.8 54** *1987*	0.1	0.0	9	**4.5 m**
3430	1956-2015	23900	0.0	NA	NA	NA	**5.5 64** *1999*	12.6	-2.2	0.4	**7.6 50 1994**	**2.0 72 1982**	**0.4 77 1981**	**0.1 149 1981**	20	**7.1** *1997*
3483	1945-2015	40000	0.0	0.0	NA	NA	**3.6 71 1966***	3.4	1.8	9.0	*5.7 46 m*	**1.3 74 2001**	*0.31 74 1998*	*-0.04 -54 m*	24	
3414	1936-2015	45300	**0.04 161 1977**	0.0	0.0	0.0	**4.3 60 1965***	7.6	3.2	5.5	**5.8 46 1982**	**1.0 51 1993**	**0.3 77 1994**	**0.1 126 1994**	*24 22 m*	**6.5 1978**
3443	1960-2015	52800	0.0	NA	NA	0.0	**15.5 79 1987**	*18.6 28* **1995**	**17.4 36** *1995*	**27.0 62 1986**	**19.0 83 1981**	**3.3 96 1992**	**0.2 44 1994**	0.0	**104 51 1995**	**6.8** *1995*
3445	1937-2015	89600	0.0	0.0	0.0	0.0	**12.4 83 1966***	**17.9 28 1988**	7.4	**24.7 63 1982**	**15.7 69 1981**	**2.1 54 1992**	**0.5 54 1987**	**0.1 75 1987**	**82 42 1987**	**4.3 m**
3861	1972-2007	224000	**0.03 79** *1981*	0.0	*-0.004 -153* **1989**	0.0	-0.8	**16.2 40** *1983*	9.4	9.2	7.8	**4.4 118 1993**	**0.4 118 m**	**0.12 75** *1982*	*60 40 1983*	

Table S4: Detected changes of monthly and annual streamflow (mm and %) and change point (year) and freshet onset dates. The Indigirka River basin

ID	Period	Area, km^2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Freshet onset dates
3516	1964- 2014	16.6	NA	NA	NA	0.0	25.7 78 1989	12.4	-9.1	18.3	36.8 111 1992	1.6 107 1992	0.0	0.0	115 32 1993	
3527	1945- 2014	23	NA	NA	NA	NA	3.9	-11.1	10.9	6.4	8.8 87 1993	0.0	NA	NA	21	4.2 m
3510	1946- 2014	644	NA	NA	NA	NA	5.2	-14.2 -61 1967*	5.3	14.0 65 1982	6.3 61 1993	0.1	0.0	NA	21	
3499	1956- 2015	7680	NA	NA	NA	NA	6.8 103 1996	11.6	- 17.6	-2.6	9.9 49 1993	3.3 70 1993	0.43 52 1994	0.0	26	5.4 m
3507	1946- 2015	17600	0.03 59 1985	0.02 91 1985	0.02 86 1985	0.01 57 1985	15.3 106 1964*	4.0	2.9	23.4 53 m	16.5 76 1993	2.1 61 1990	0.6 88 1988	0.1 80 1987	81 39 1995	7.6 1967
3518	1945- 2015	22300	0.0	NA	NA	NA	11.8 90 1966*	-12.3	-3.2	3.9	9.1 51 1993	0.9 34 1966*	0.2 47 1994	0.0	14	3.9 1967
3488	1956- 2015	51100	0.1	0.10 54 2003	0.11 67 2004	0.10 56 2002	7.6 97 1980	9.9	-4.4	7.6	12.5 59 1993	2.3 45 2002	0.4 25 1999	0.0	43	5.1 m
3489	1944- 2015	83500	0.14 64 2006	0.10 86 1977	0.10 120 1983	0.14 159 1981	7.4 92 1966*	-0.6	-6.0	13.2 34 m	11.4 55 1993	1.4 34 1993	0.4 28 1982	0.3 63 1983	33 19 1995	4.6 1967
3871	1936- 1996	30500 0	-0.08 -25 1964*	-0.01	0.01	0.01	0.2	0.3	-6.3	4.3	11 49 1965	0.7	-0.1	-0.2 -32 1969	8.1	

Table S5: Detected changes of maximum water discharges in May – September (m^3s^{-1} and %) and change points (year).

Only those gauges are included into the table, where the changes were identified.

ID	May	June	Jul	Aug	Sep
3516					0.71 65.5 1993
3527					0.22 54.1 1965, 1971
3510		*-13.5* *-47.7* *m*		*17.5* *69.9* *1982*	5.3 47.4 1993
3499	*62.0* *64.8* *m*				63.4 43.3 m
3507	431 83.4 1964				298 78.3 1981, 1993
3518	403 72.0 1987, 1966				183 44.8 1971, 1993
3488	384 59.4 1987, 1984				445 58.7 1993
3489	848 71.2 1965				794 58.9 1973, 1993
3478			0.85 84.4 m		
3479		163 81.8 1994		96 62.6 1987	49 68.2 m
3424					*93.6* *53.3* *m*
3430	196 49.4 1999				*116* *36.4* *m*
3483					*158* *31.8*
3414	495 85.2 1964				239 50.3 1976, 1995
3443			1100 46.7 m	1021 48.8 m	815 70.5 *1981*
3445	1520 65.6 1988, 1966			1631 55.8 1986, 1984	985 59.8 1981
3861				*1298* *26.4* *1984*	

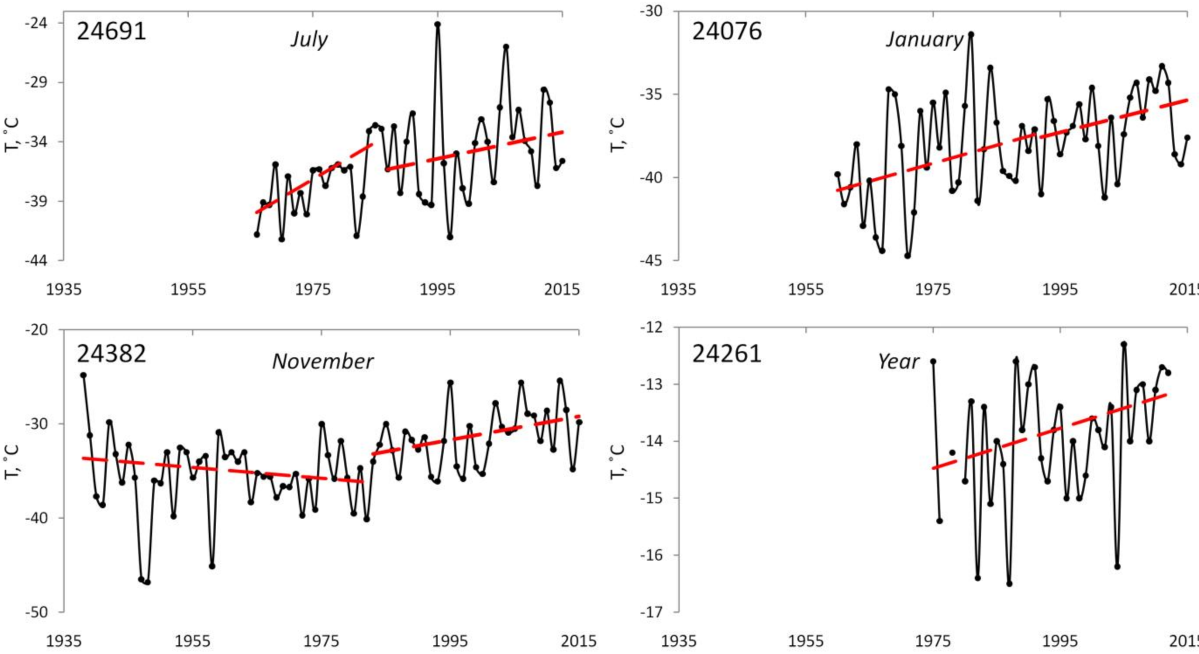

Fig. S1 Changes of air temperature at some meteorological stations of the studied region

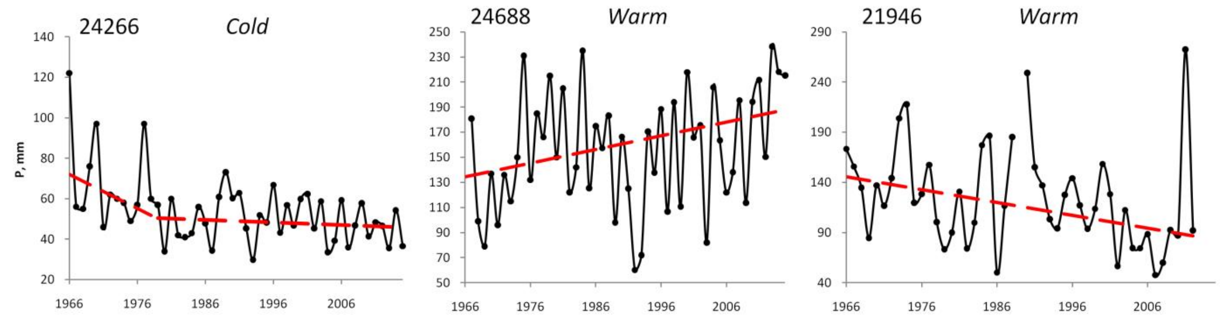

Figure S2: Changes of precipitation at some meteorological stations of the studied region

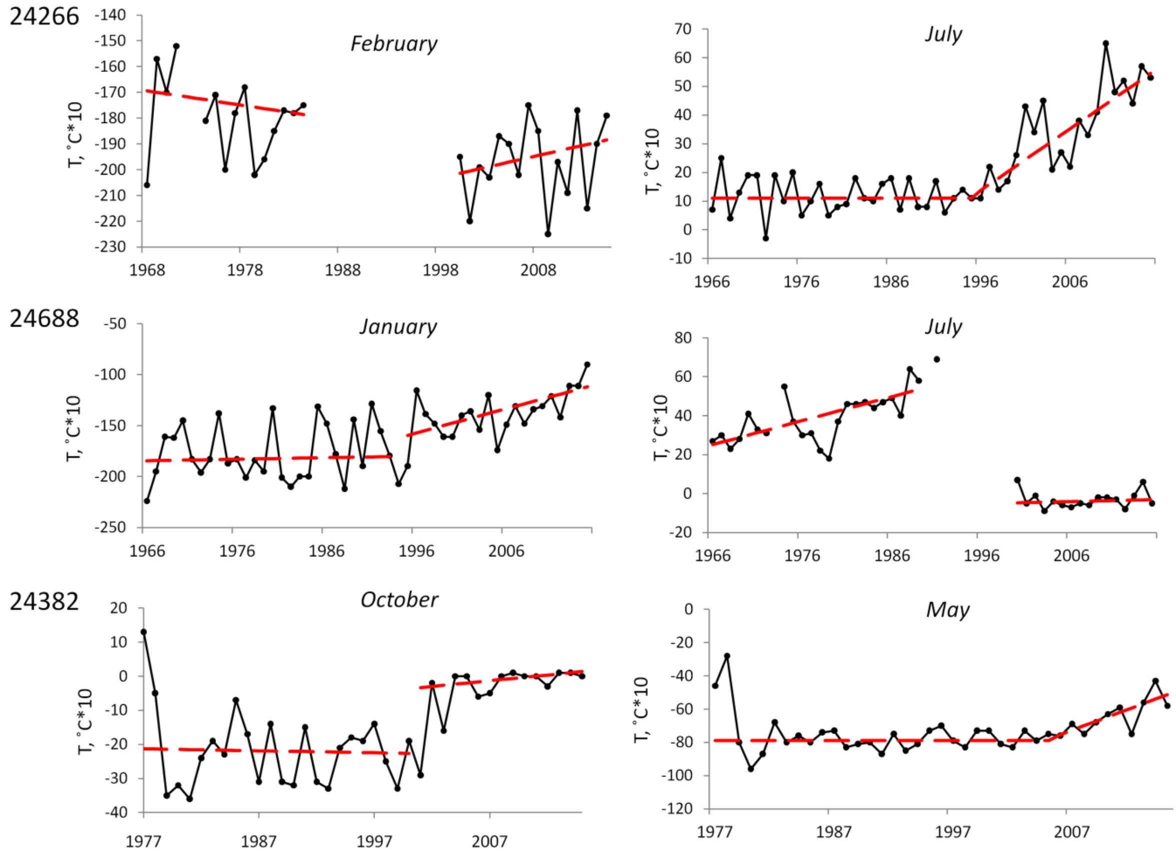

Figure S3: Changes of monthly soil temperature at 80 cm depth at the Verkhoyansk (ID24266), Oymyakon (ID24688) and Ust'-Moma (ID24382) meteorological stations, 1966 (1977)-2015. Red dash line is Sen's estimate. The year of change point where continuous data is available was estimated with the Pettitt's test at p ≤ 0.05

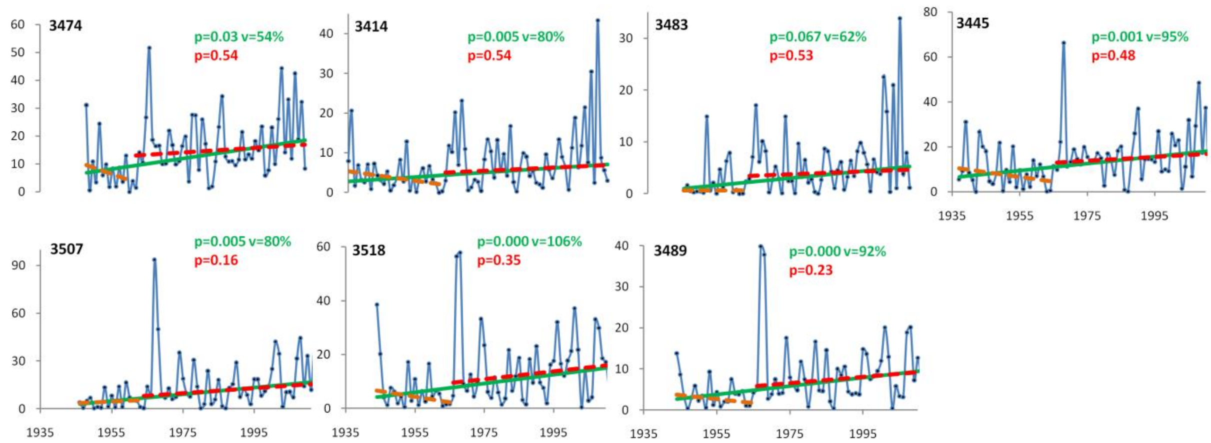

Figure S4: Patterns of streamflow changes in May, group A (green, orange and red – the trend slope over the period of record, before and after change point respectively)

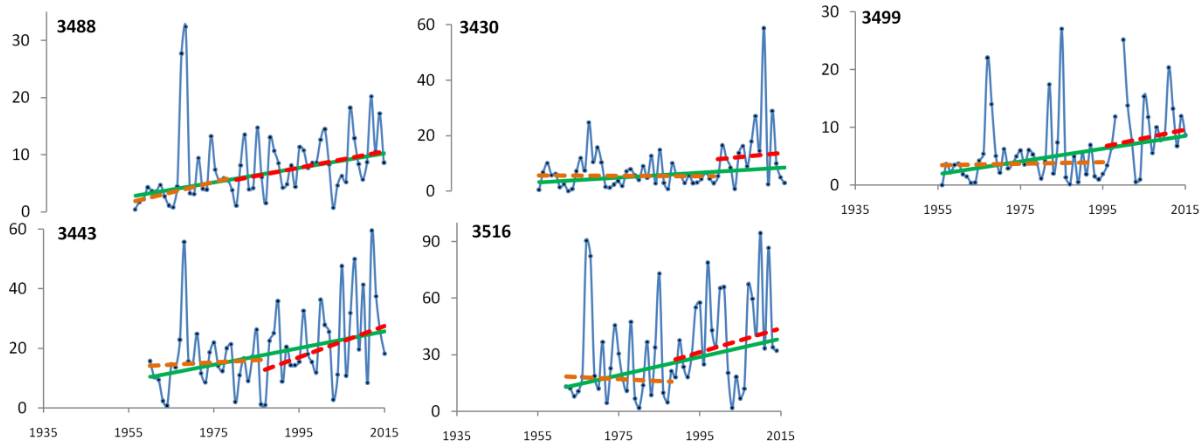

Figure S5: Patterns of streamflow changes in May, group B (green, orange and red – the trend slope over the period of record, before and after change point respectively)

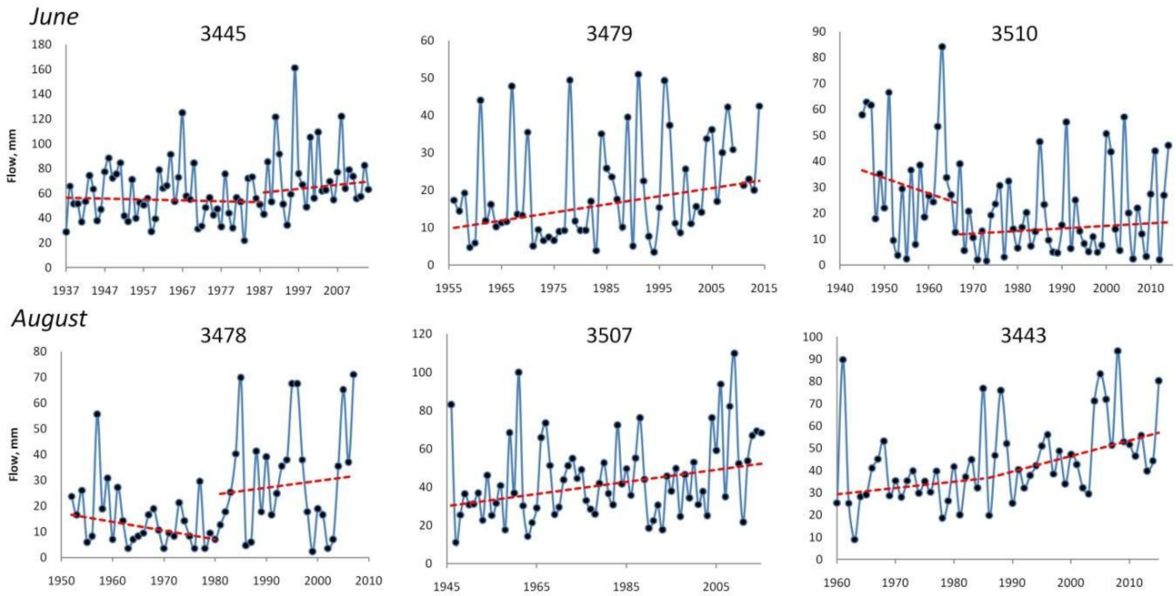

Figure S6: Changes of streamflow in June and August

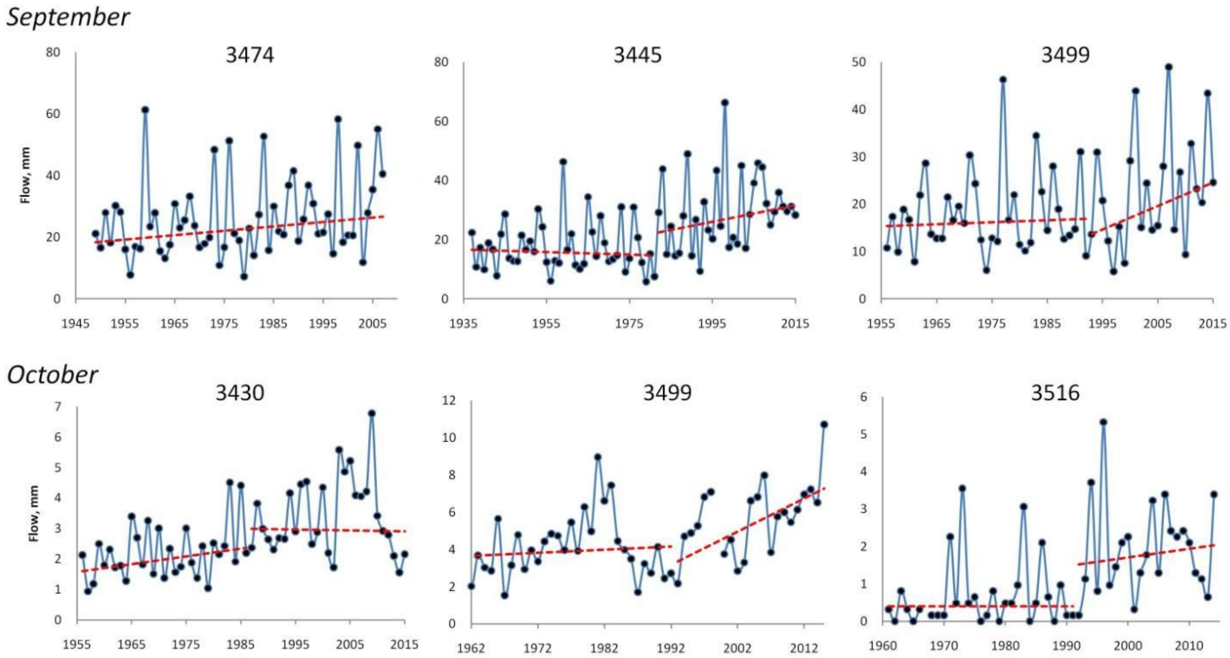

Figure S7: Changes of streamflow in September and October

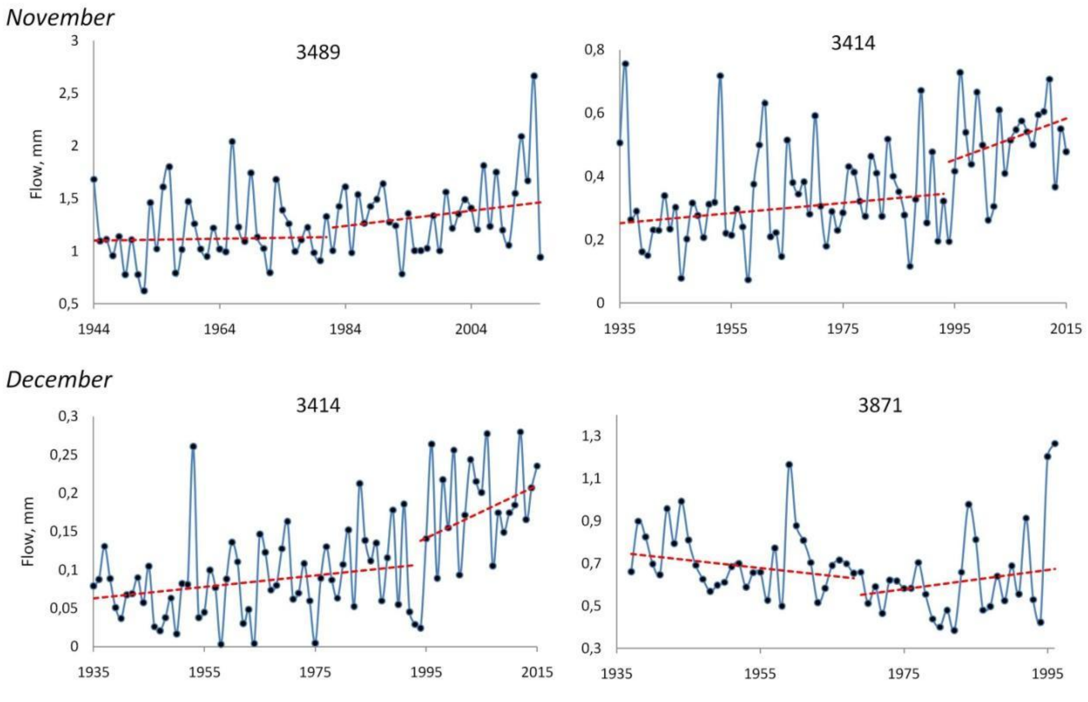

Figure S8: Changes of streamflow in November and December

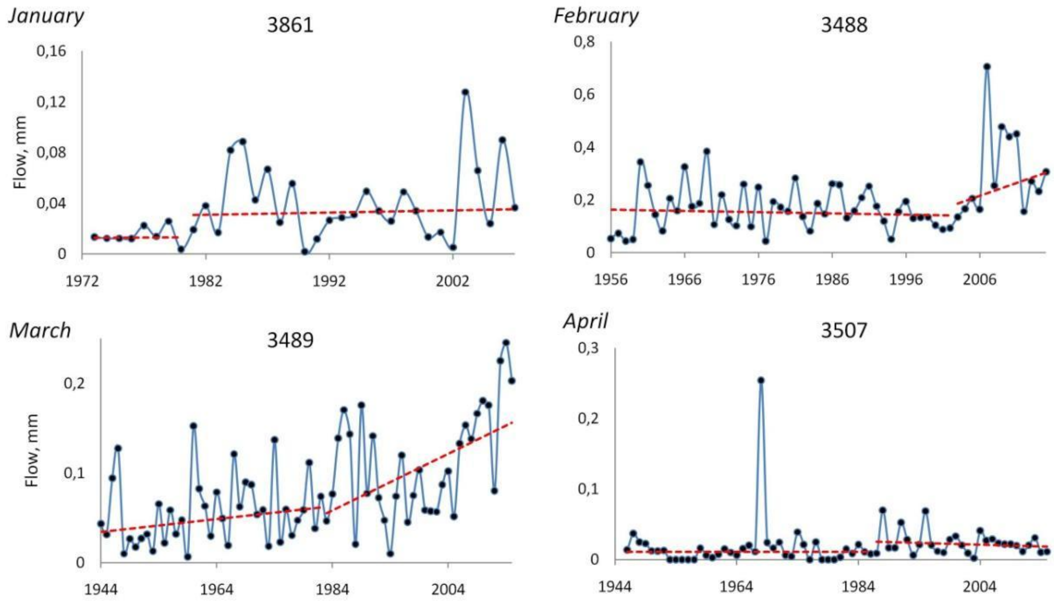

Figure S9: Changes of streamflow in January – April

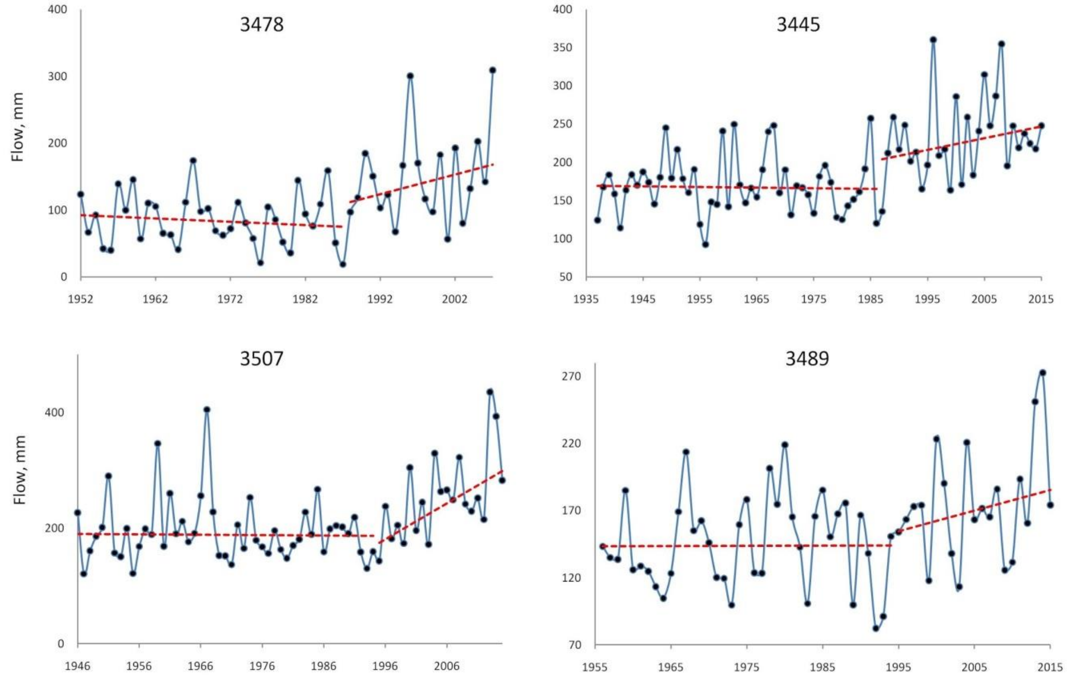

Figure S10: Changes of annual streamflow

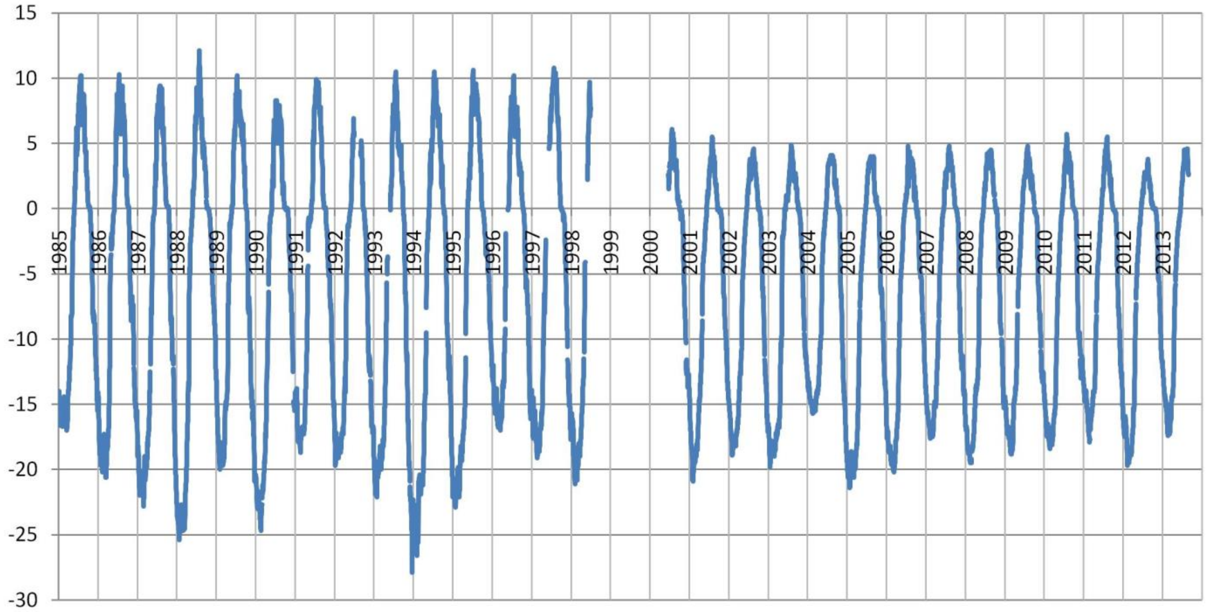

Figure S11: Soil temperature at Oymyakon (ID 24688) at 0.4 m depth, 1985-2013. One may note abrupt change of maximum soil temperature after data gap in 1999-2000.

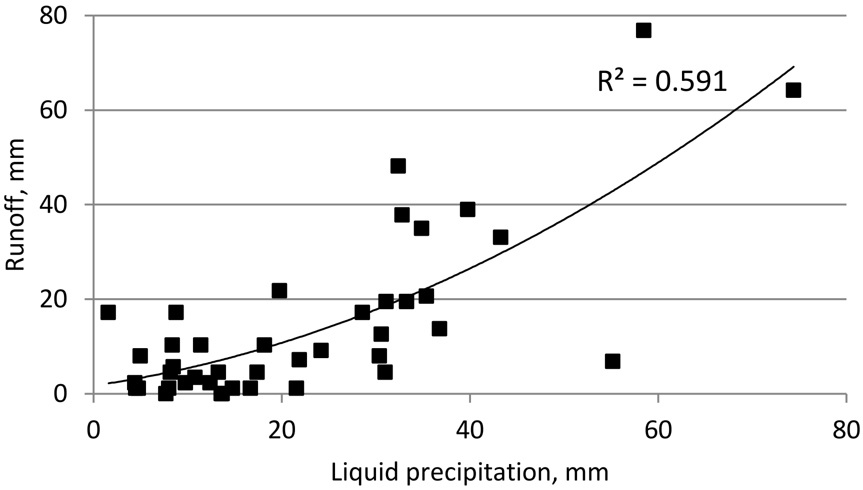

Figure S12: Correlation of runoff and liquid precipitation in September, Ust-Charky meteorological station (ID 24371) – gauge ID 3478

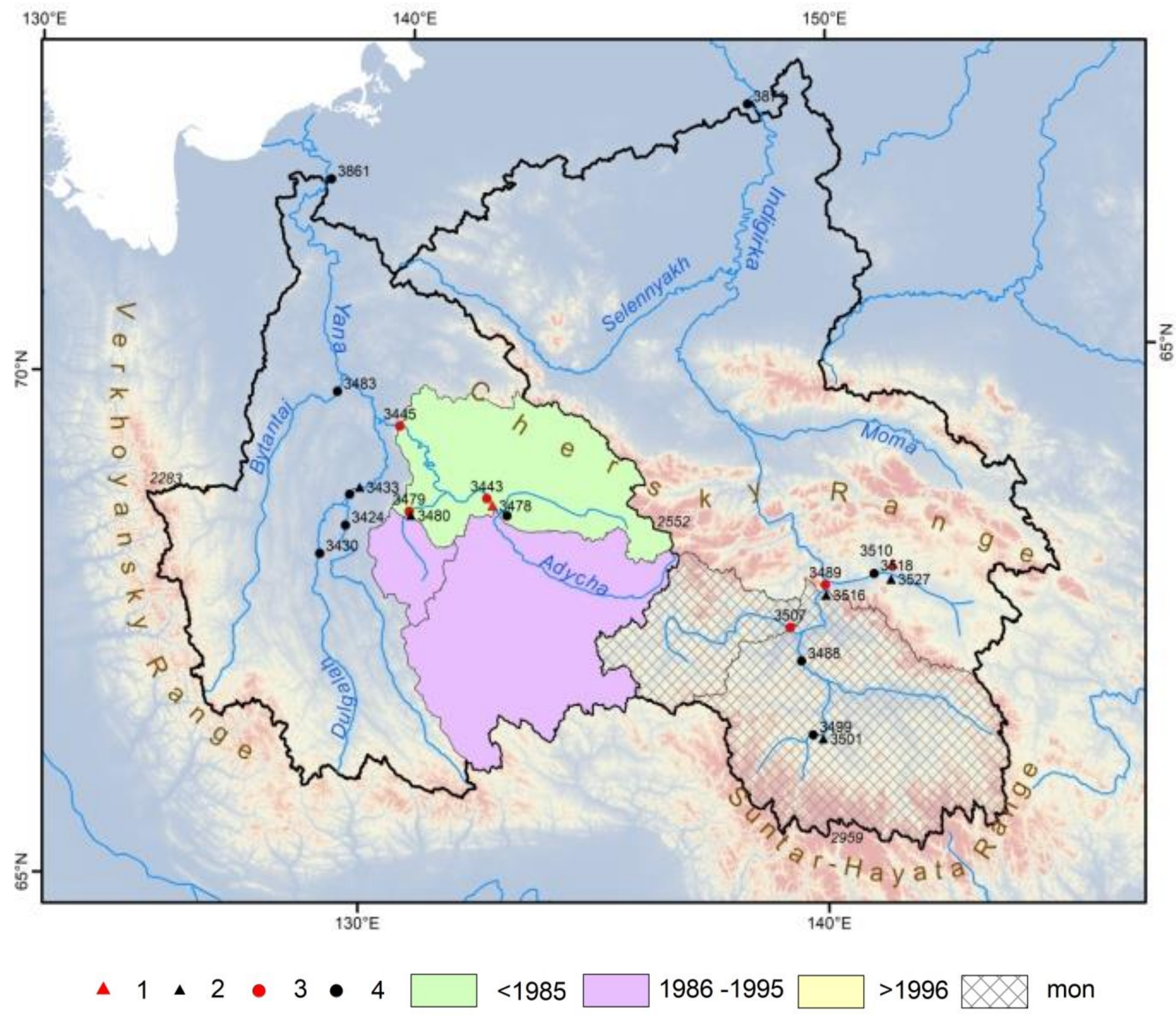

Figure S13: Changes of streamflow in August. Here and in following Fig. S14 – S18: statistically significant trends values are divided into 4 groups and painted with different colours accordingly: change points < 1985 – green, 1986-1995 – violet, 1996 and later – yellow, check - monotonically trends. 1 – gauges with significance changes (basin area < 1000 km^2), 2 – gauges without significance changes (basin area < 1000 km^2), 3 - gauges with significance changes (basin area > 1000 km^2), 2 – gauges without significance changes (basin area > 1000 km^2)

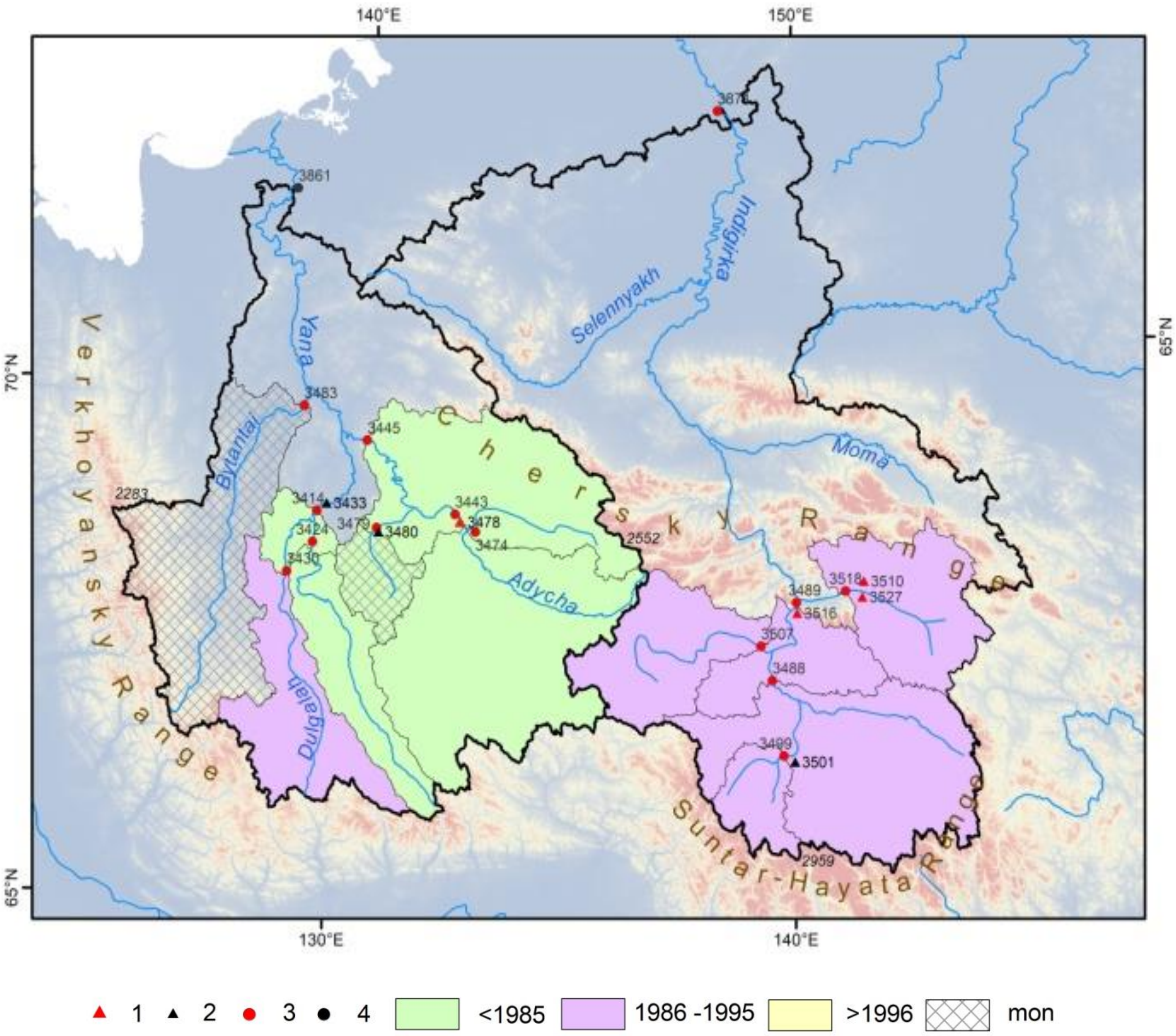

Figure S14: Changes of streamflow in September. All designations are the same as in Fig. S13.

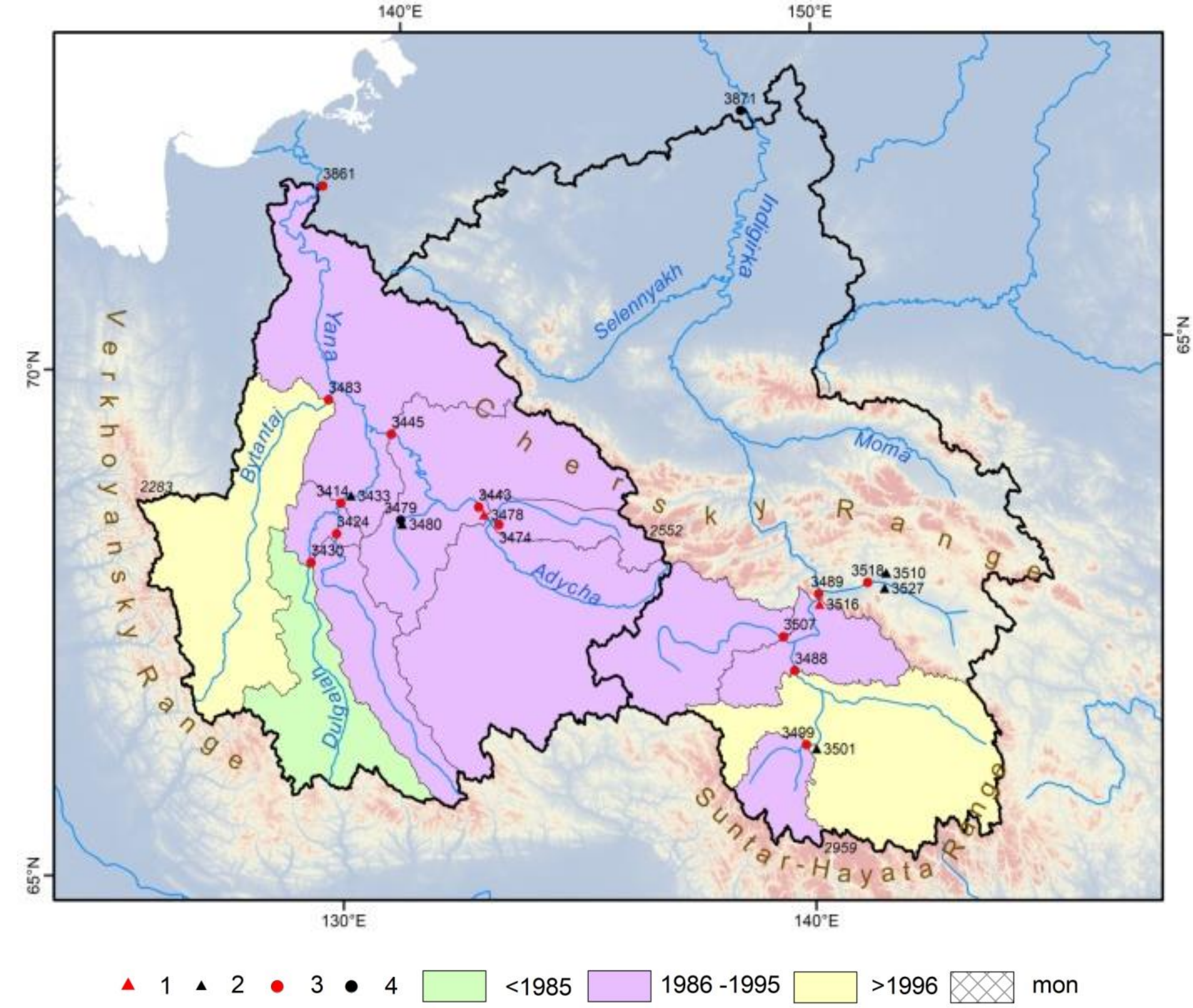

Figure S15: Changes of streamflow in October. All designations are the same as in Fig. S13

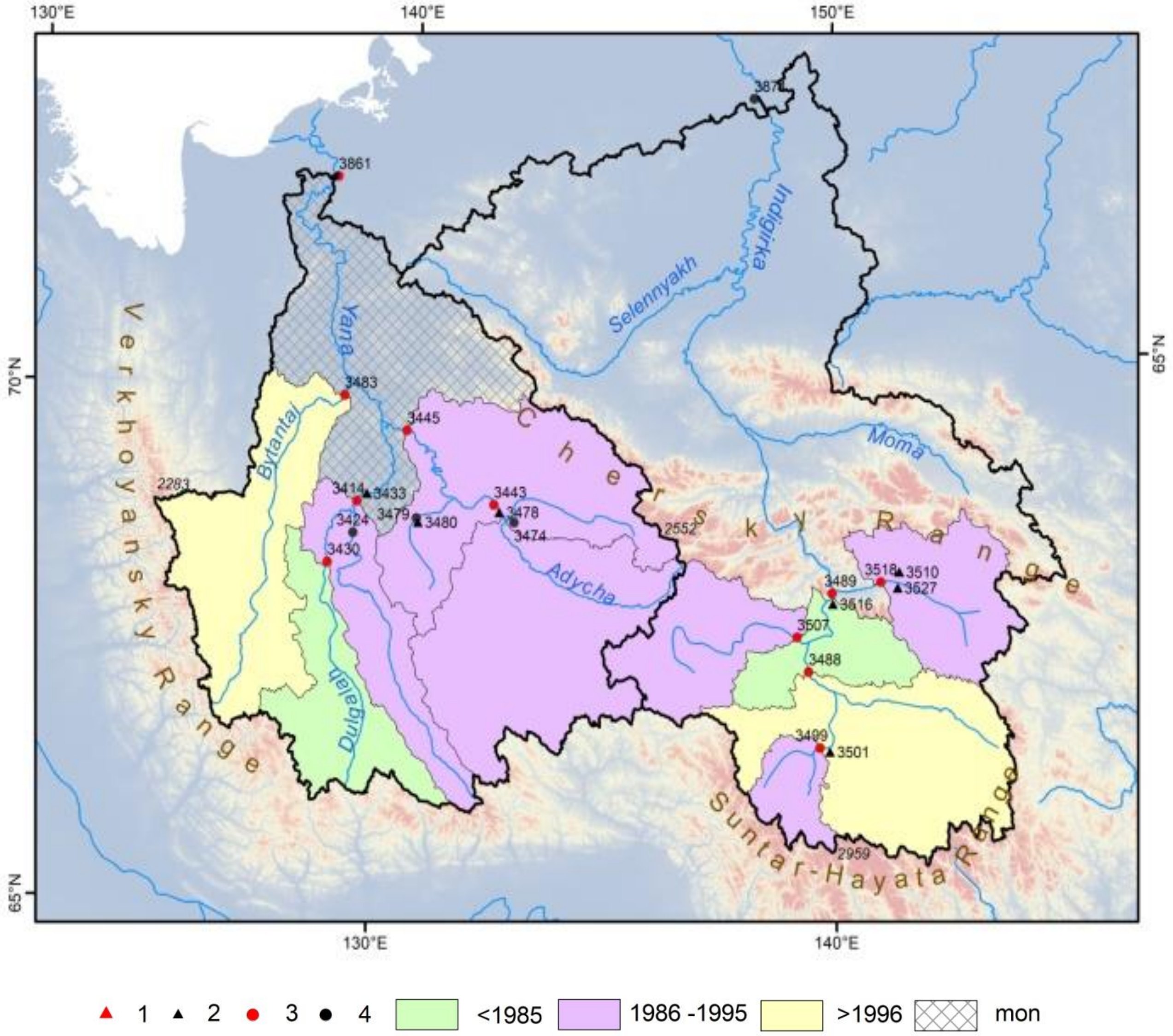

Figure S16: Changes of streamflow in November. All designations are the same as in Fig. S13.

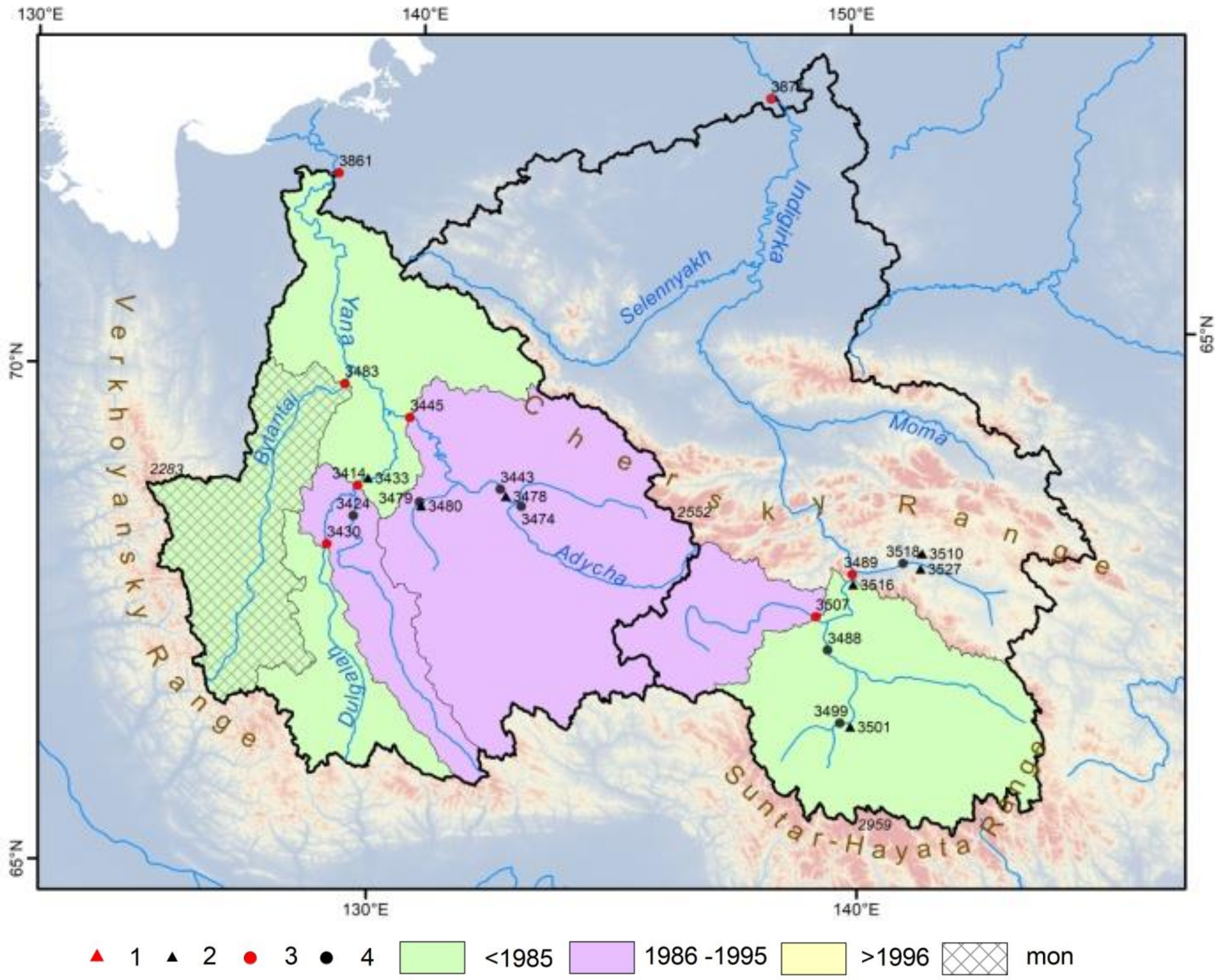

Figure S17: Changes of streamflow in December. All designations are the same as in Fig. S13.

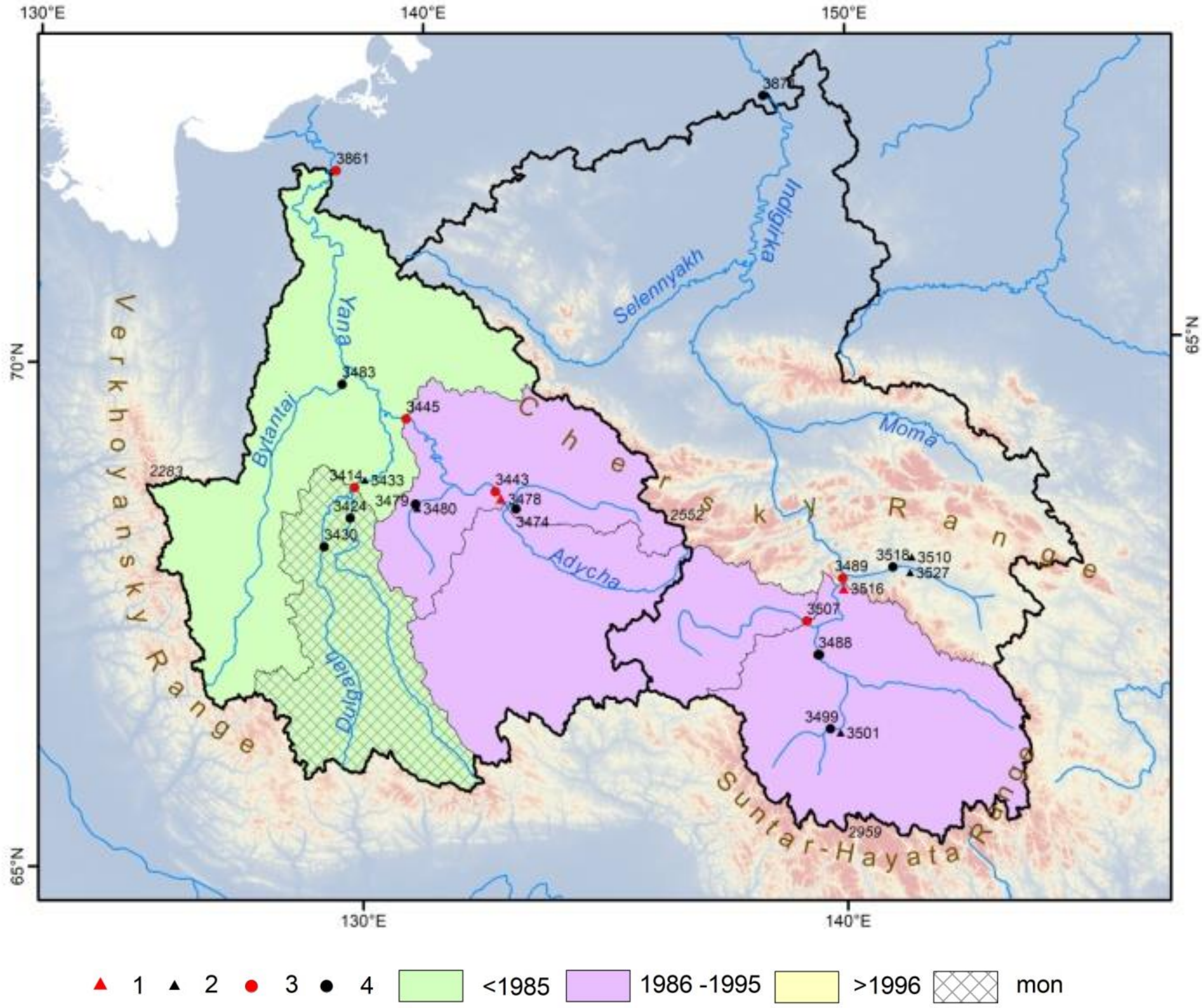

Figure S18: Changes of annual streamflow. All designations are the same as in Fig. S13.